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Bullet Fragmentation: A Major Cause of Tissue Disruption

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Effects of nonfragmenting solid brass bullets (5.56 mm, 3.1 gm, 1.9 cm long, machine-made at Letterman Army Institute of Research) and fragmenting soft-point bullets (5.56 mm, 3.2 gm, 1.7 cm long, commercially made by Hornady Manufacturing Co., Grand Island, NE) were compared when they were fired through soft tissue of the hind legs of five live swine (50 to 70 kg). The swine were anesthetized endotracheally (0.8% halothane) and placed in the supine position with the hind legs extended. Blocks of tissue simulant (10% gelatin at 4°C, molded in blocks 20 × 22 × 47 cm) were placed against the skin at the predicted point of bullet exit. All shots (a fragmenting bullet through one hind leg and a nonfragmenting bullet through the other hind leg of each swine) were fired at a range of 3 m from a rifle with a bullet tract at 90° to the long axis of the swine's body. Bullet velocities ranged from 930 to 990 m/s. Dissections of the bullet tract (through tissue and gelatin) revealed that tissue disruption from the fragmenting bullets was significantly greater ($p < 0.001$) than from nonfragmenting bullets. The recovered bullets were weighed. The results showed that the fragmenting bullet lost 59 to 77% of its original weight and the nonfragmenting bullet was the same weight as originally. Recognition of the amount of tissue disruption and identification of bullet fragments in the wounds resulting from the two different bullets should be a useful guide to operating surgeons in selecting the best approach for treatment of gunshot injuries.

Some knowledge of wound ballistics—the scientific study of the speed and direction of missiles in relation to the injuries they produce (Dorland)—is prerequisite to the adequate treatment of gunshot wounds. Essential to the study of wound ballistics is an understanding of the mechanism of wounding, i.e., the physical-mechanical events that take place when a bullet strikes body tissue. In the published wound ballistic studies, bullet fragmentation—the separation or splitting apart of a portion or all the bullet into smaller pieces—has not been recognized as a major cause of tissue disruption.

In 1935, Callender and French (5) reported effects of nonfragmenting solid brass bullets. They reported two shots, one at 924 m/s and the other at 1,088 m/s. Since the shots produced extensive wounds, they concluded that it is *not* necessary for the bullet to fragment in order for massive amounts of tissue to be damaged at "the higher velocities." Interpretation of their conclusions may be one reason bullet fragmentation has been overlooked as a significant factor in the mechanism of wounding. Their experimental design shows that the shots hit both hip joints of a live goat. Thus their results show that a bullet of sufficient energy causes a great deal of tissue damage when it hits bone. Actually, the multiple bone fragments acted as secondary missiles, but apparently this factor was not recognized. Therefore, to apply Callender and French's findings (5) to gunshot wounds where no bone is struck by the bullet is invalid.

Our study was designed to determine the relationship of bullet fragmentation to tissue disruption where only soft tissue is penetrated (no bone is struck) by the bullet. The effects of fragmenting and nonfragmenting bullets fired through tissue simulant and live swine striated muscle were compared.

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In conducting the research described in this report the investigators adhered to the "Guide for Laboratory Animal Facilities and Care" as promulgated by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences, National Research Council.

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MATERIALS AND METHODS

The study to determine the relationship of bullet fragmentation and tissue disruption in living muscle was preceded by a study to find a tissue simulant which would have approximately the same resistance to bullet penetration as living swine striated muscle. Ten per cent gelatin at 4°C fulfilled this criterion, as determined by penetration comparisons. The tissue simulant was molded into 20 × 22 × 47 cm blocks. Two types of bullets were compared throughout this study. One was a commercial 5.56-mm, 3.2-gram soft-point, 1.7 cm long (Hornady Manufac-

turing Co., Grand Island, NE) and the other was a pointed solid brass bullet similar to the soft-point bullet: these brass bullets (5.56 mm, 3.1 gm, 1.9 cm long) were machine-made at the Letterman Army Institute of Research, San Francisco, California. The soft-point bullet fragments in a predictable and reproducible manner on impact with tissue or tissue simulant. The solid brass bullet does not fragment on impact with tissue or tissue simulant. Before making the solid brass bullets, several full metal-cased bullets (this type of bullet is considered to be *nonfragmenting*) of the standard copper jacket lead core construction were tried and all of them fragmented at the velocities we used for this study.

Three shots were made into gelatin blocks with each of the two bullet types. Fresh gelatin blocks were used for each shot. The entire track of the bullet and fragments was visibly recorded in the transparent gelatin. Penetration of the bullet was measured by slicing the gelatin along the bullet tract. The diameter of the widest dispersion of fragments was measured on the sliced gelatin blocks, as was the penetration depth at which this widest dispersion occurred. The bullets were recovered and weighed. The loss in weight was equal to the weight of the fragments that had been shed from the bullet along its track. Per cent fragmentation was calculated by dividing loss of weight by total bullet weight.

In the living tissue study, 5 swine weighing 50 to 70 kg were anesthetized with 0.8% endotracheal halothane and placed in the supine position with a hind limb held in the extended position so that the shot penetrated the thick proximal portion of the limb. All shots were made transversely: the bullet tract at 90° to the long axis of the swine body. Each swine had a soft-point bullet fired into one hind limb and a solid brass bullet into the other. Gelatin blocks were placed against the skin of the swine at the predicted point of bullet exit so that the entire tract of the bullet would be captured for calculation of total penetration (swine leg plus gelatin penetration) and the bullet was recovered for weighing. Roentgenograms of the wounded areas were obtained to determine the location of bullet fragments. Wound tracts were dissected anatomically. Cross-section diameter of each permanent wound tract at its widest point and the penetration depth at which this maximum tissue disruption occurred were measured. The swine were killed (intravenous pentobarbital sodium) while still under anesthesia. The recovered bullets were weighed on a Redding powder scale sensitive to ±5 mg (Redding, Inc., Cortland, NY).

All shots were made at a range of 3 m from a 5.56-mm barrel with a rifling twist giving one revolution of bullet per 30.48 cm of barrel traversed. Bullet velocities were measured with a chronograph composed of two counters (Model 464T, Electronic Counters, Inc., Syosset, NY) connected in parallel (one serving as a check on the other), and the impulses were generated by the bullet breaking a circuit of fine metal foil printed on thin paper. Screens were spaced 50 cm apart and placed midway between the rifle muzzle and the target.

RESULTS

Numerical results of the six shots into gelatin are listed in Table I. This study revealed a marked difference in penetration: 55.4 cm for the nonfragmenting brass bullets and 21.8 cm for the fragmenting soft-point bullets.

Numerical results of the shots through living swine muscle are listed in Table II. The results are also shown diagramatically in Figure 1 and photographically in Figure 2. The marked differences in penetration of the two bullet types seen in the gelatin study were reproduced in the swine muscle study.

TABLE I
Comparison of nonfragmenting and fragmenting bullets in gelatin (Mean ± SD)

	Solid Brass	Soft-Point
Bullet weight (gm)	3.1	3.2
Number of shots	3	3
Velocity (m/s)	961 ± 27	959 ± 14
Penetration (cm)	56.8 ± 0.76	21.8 ± 0.76†
Weight of recovered bullet (gm)	3.1 ± 0	0.73 ± 0.05
Per cent bullet fragmentation	None	77.3 ± 1.53
Diameter of maximum fragment spread (cm)	N/A*	7.8 ± 0.29
Penetration at which maximum fragment spread occurred	N/A*	9.7 ± 0.76

* Not applicable.
† $p < 0.001$.

TABLE II
Comparison of nonfragmenting and fragmenting bullets in living swine (Mean ± SD)

	Solid Brass	Soft-Point
Bullet weight (gm)	3.1	3.2
Number of shots	5	5
Velocity (m/s)	961 ± 9.42	960 ± 6.18
Penetration (cm)		
Swine	25 ± 1.22	21.8 ± 0.57
Gelatin	30.4 ± 1.52	0
Total	55.4 ± 1.14	21.8 ± 0.57*
Weight of recovered bullet (gm)	3.1 ± 0	1.3 ± 0.2
Per cent bullet fragmentation	0	59 ± 6.11
Permanent wound tract maximum diameter (cm)	1.8 ± 0	7.4 ± 0.31*
Penetration at which maximum fragment spread occurred	28.4 ± 1.14	10.4 ± 0.65

* $p < 0.001$.

The differences in cross-sectional area of the permanent tissue disruption can be seen most clearly by comparing the holes produced by the two types of bullets (Fig. 2), where 1-cm thick slices of muscle cut at a right angle to the bullet tract are shown. The pieces of completely detached muscle are shown in the wound cavity of the soft-point bullet (Fig. 2).

All of the solid brass bullets ended up in the base forward position in the gelatin (Fig. 1), proving that they had passed through the maximum 90 degrees of yaw (yaw is the tilting of the bullet's long axis from the line of flight; at maximum yaw the bullet is traveling sideways).

DISCUSSION

Bullets intended to be shot at velocities over 500 m/s are two basic types: the nonexpanding military bullet (full metal jacketed, full metal cased) and the expanding hunting bullet (usually soft-point or hollow-point) (Fig. 3). DeMuth (6) demonstrated, in anesthetized dogs, the marked difference in tissue disruption caused by these two types of bullets. He shot dogs through the chest cavity side-to-side laterally with a 7.62-mm 9.7-gm full metal-cased bullet and compared the wounds with those

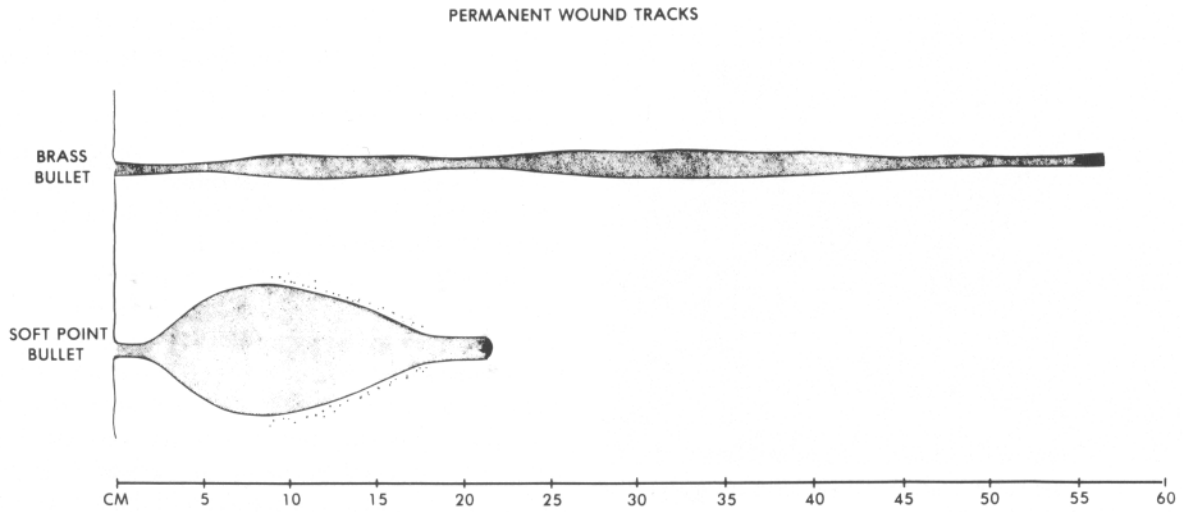

FIG. 1. Diagram comparison of typical permanent wound tracts. Based on data from Tables I and II.

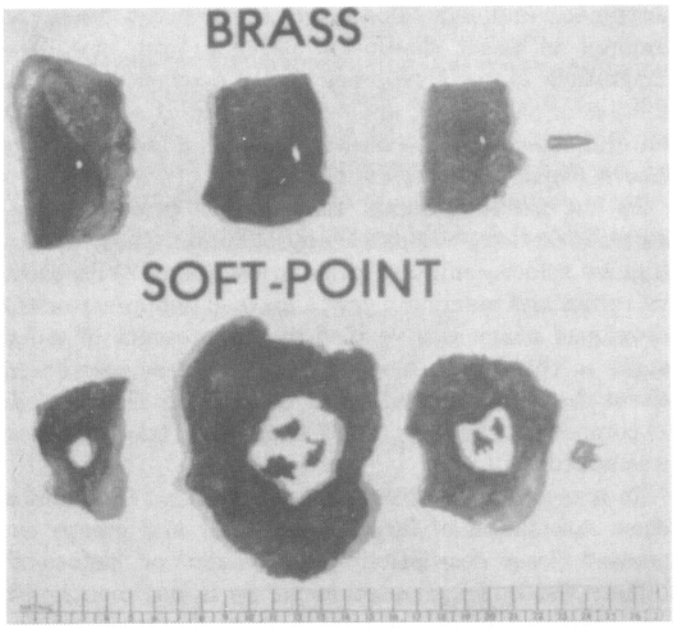

FIG. 2. Photographs of comparative sections of both wound tracts taken at 3, 12, and 20 cm penetration.

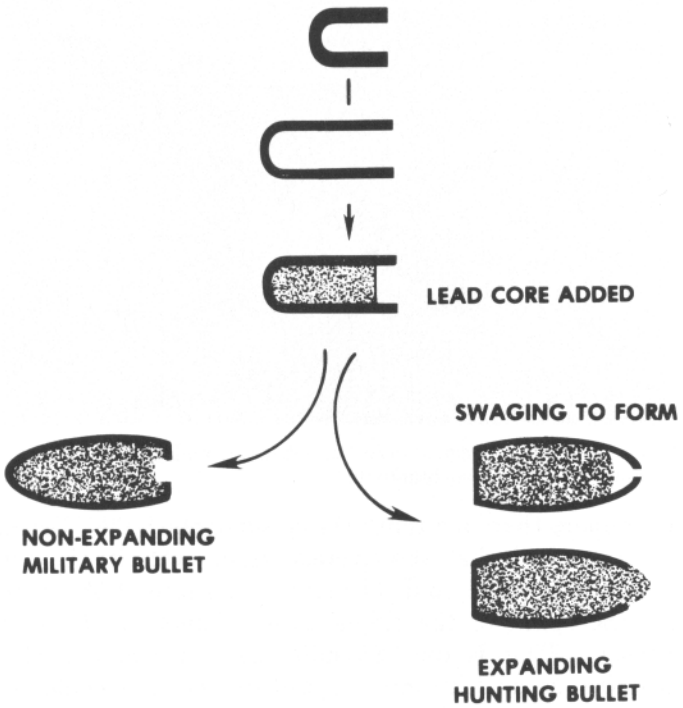

FIG. 3. Diagram showing basic bullet construction difference between military and hunting bullets.

produced by a soft-point bullet of the same caliber and weight. The velocity of both bullets was 884 m/s. Entrance wounds were the same (0.75 cm), but the exit wound of the soft-point bullet measured 12.5 cm in diameter while the full metal-cased bullet caused a wound of less than 2 cm diameter. DeMuth's data are in close agreement with our findings, which show a marked increase in tissue disruption associated with the expanding soft-point bullet. DeMuth's explanation of the physical-mechanical events responsible for the massive wound caused by the soft-point bullet was: 1) that the bullet expands to several times its original diameter, thus making a wide wound tract; and 2) that "all tissue cells lying ajacent to the wound tract become secondary missiles which move outward at enormous speeds to give rise to the temporary cavity." These explanations are repeated frequently in the wound ballistics literature.

We question DeMuth's interpretation of his findings (6) for the following reasons: 1) if an expanding bullet increases its diameter three times, simple arithmetic suffices to show the inadequacy of this explanation (7.62 mm × 3 = 2.29 cm, which leaves more than 10 cm of exit wound unexplained); and 2) if one looks at a high-speed roentgenogram (page 56, Fig. 3-17 in *Vascular Trauma*, Rich and Spencer, Saunders, Philadelphia, 1978, for example) and measures the distance the bullet travels from any point on its path and compares this distance with the distance the tissue edge has moved away from the same point on the bullet path, one finds that the bullet has traveled about ten times as far as the tissue in the same time period. The speed of the tissue, therefore,

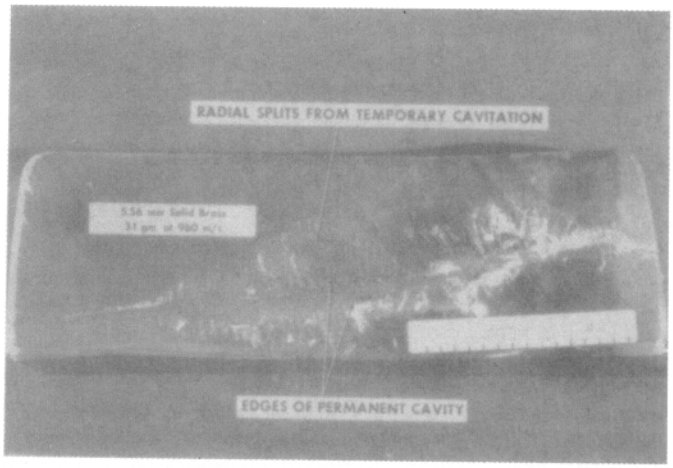

FIG. 4. Tract of brass bullet in gelatin (tissue simulant study). The block is split in axis of bullet tract.

FIG. 5. Typical fragmentation of soft-point bullet, shown here in roentgenogram of swine hindlimb.

is no more than one-tenth the speed of the bullet. Beyer (4) remarked that the average tissue velocity is not particularly great, and calculated the figure of 38.1 m/s for the speed of the tissue with a bullet of 762 m/s velocity. That is only 85 miles per hour and hardly qualifies as an 'enormous' speed or one that could be expected to cause the damage attributed to it.

The nonexpanding military bullet generally causes minimal tissue disruption and remains undeformed as does the brass bullet in our study. The military bullet *can* cause massive tissue disruption under certain circumstances if it: 1) hits bone; 2) hits a hard object, such as a belt buckle, before entering the body; 3) is a ricochet; or 4) has been altered. Filing of bullet tips to make the full metal-cased bullet more lethal has been described as a common practice in the late nineteenth century (7) and has probably occurred sporadically in more recent campaigns.

We have shown that the soft-point bullet, in addition to 'expanding' its diameter, also loses from 59 to 77% of its weight in fragments which are widely distributed in the tissues over an area up to 8 cm in diameter. It appears that this fragmentation is the critical factor in the increased tissue disruption caused by these bullets. We suggest that the multiple fragments are likely to cut across many muscle bundles in two places and that the piece between cuts is then likely to be completely detached by the subsequent sudden stretch of the temporary cavitation. Tissue weakened by fragment passage may be split by a stretch that would otherwise be absorbed by the tissue's elasticity.

Even after Rich et al. (10) commented on the typical spatter of lead fragments in wounds with large gaping exits and loss of large amounts of tissue, suspicion was not aroused that bullet fragmentation might be the primary mechanism causing the marked increase in tissue disruption. Instead, bullet yaw (frequently called tumbling) was invoked as the cause. Indeed, it is difficult to find a text or chapter on wound ballistics written in the last 15 years that does not include a diagram of a yawing bullet. The yaw explanation also fails the test of simple arithmetic and logic. The length of the bullet limits the amount of tissue disruption psosible from yaw. The magnitude of the temporary cavity does increase with increasing yaw angle, analogous to that of a high diver entering the water: the larger the angle of the body to its line of flight, the more the disturbance of the water.

In the tissue simulant studies with brass nonfragmenting bullets, velocities approximated those of the highest velocity military rifles in use today. With these velocities and maximum yaw, a marked temporary cavity developed which was verified by the presence of radial splits in the gelatin blocks (Fig. 4), yet the permanent tissue disruption was minimal (Tables I & II; Figs. 1 & 2) compared to that produced when bullet fragmentation was added.

In a recent paper from China, Liu et al. (9) noted a close association of large exit wounds and greatly increased tissue disruption with 'broken' or 'deformed' bullets. Bullet fragmentation per se is not mentioned, but scattered pieces of muscle were described on the chronograph screens with the 'broken' or 'deformed' bullets. In our laboratory, detached pieces of muscle (either free in the wound cavity or in the gelatin block) have been a constant factor in all wounds produced by fragmenting bullets and have not been seen when the bullet remained in one piece. This observation is not limited to the present study but has been noted with a variety of missiles fired in our laboratory at velocities up to 1,900 m/s (unpublished data). Thus it appears most likely that the findings of Liu et al. (9) support our data. The experimental design of Liu et al. (9) mimics the popular 'energy deposit' format, which is unlikely to detect fragmentation. In the 'energy deposit' design, the bullet passes through two chronographs, one before and one after perforating the target. Velocity loss is determined by subtracting exit from entrance velocity, and then energy loss or 'deposit' in the target is calculated. This determination is valid *only* when the weight of the missile remains constant. If a bullet loses fragments in

the target, it will weigh less when passing through the second chronograph and carry less energy when leaving the target. When fragmentation occurs, therefore, the deposited energy figures will be falsely low. The 'energy deposit' studies in the literature since 1967 have used at least one bullet that fragments frequently. None of these investigations (1–3, 8, 9, 11, 12) reported a methodology that includes catching and weighing the bullets to detect and correct for bullet fragmentation. Therefore, one must suspect a fallacy in calculation of the 'energy deposit.'

In this paper, we have provided evidence which indicates that the mechanism of bullet fragmentation is responsible for a massive tissue disruption in living swine muscle at velocities between 930 and 990 m/s. The mechanisms of bullet yaw (tumbling) and temporary cavitation are responsible for only a minor permanent tissue disruption in living swine muscle at velocities up to 990 m/s.

The results of our laboratory studies on wound ballistics have two useful clinical applications. From roentgenograms of the wounded area (Fig. 5), the surgeon can recognize the presence of fragmentation, which assists in estimating the magnitude of tissue disruption. Also, the location of fragments can guide him in selecting the incision site.

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